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DESIGN An APPROACH FOR PERFORMANCE ANALYSIS OF PROTECTED AND UNPROTECTED HIGHY STRENGTH STEEL STRUCTURES UNDER FIRE CONDITIONS

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Abstract: Because of its great performance and its capacity to cut down on the overall amount of material used in a project, high strength steel is becoming an increasingly preferred material choice for the construction of civil engineering projects. The overall structural behaviour of frames built from high strength steel will be investigated in this research, which will build upon prior work done at Brunel and explore the behaviour of frames under fire. Students who are interested in obtaining a fundamental understanding of the way that steel structures respond in a fire using finite element analysis are the ones who will benefit the most from participating in this project. It would be helpful if you had experience or an interest in structural fire engineering as well as finite element modelling. Additionally helpful is prior experience in the relevant field (please provide sufficient details in your personal statement so that its relevance can be established). Candidates will either already possess or be required to earn a bachelor's degree in engineering with a grade point average of at least 3.0 (or its international equivalent). There is no requirement for a postgraduate master's degree, however having one could be beneficial. It would be helpful if you have previous experience with MATLAB, finite element modelling, and structural engineering. It would be beneficial to have knowledge of structures as well as finite element modelling. Additionally, he or she needs to be highly driven, capable of working in a team, collaborating with others, and have excellent communication skills.

Keywords: Unprotected High, Strength Steel Structures, Fire Conditions.

Introduction

It is essential that the structure of the building be safeguarded against the spread of fire at all costs. The process of combustion causes a transfer of energy from a state that is relatively stable to one that is more prone to fluctuations. A building that has been designed with fire safety in mind will have a slower rate of energy transmission, which will buy the occupants additional time before the structure finally collapses. When fire loading is the predominant component contributing to the breakdown of the structure, the technique by which fire might be localised in these instances is called compertmentation [1]. This study's objective is to explore the fire prevention measures that are already in use and to determine both the positive and bad elements associated with such approaches. The goals of this investigation are to investigate the various methods of fire protection; investigate the instances of fire damage to structures that have been

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documented in the past; investigate some properties and fire-related tests of steel structures; and investigate some practical fire-protected steel structures. There has only been a limited number of research projects that have been carried out that are based on fire experiments [2]. This is primarily due to the significant cost that is required. It is taking a very long time because of this for them to figure out how steel responds when it is heated, and even longer for them to construct a model based on their results.

Related Work

Nadjai, Ali, et al.(2016) An experimental examination at elevated temperatures on the behaviour of full-scale composite floor unprotected and protected cellular steel beams with intumescent coatings with different opening sizes and shapes is the goal of this work. Each beam was designed with a full shear connection between the steel beam and the concrete flange, which was achieved by employing headed shear studs in the construction of the steel beam. Temperatures are unevenly distributed across a composite member when it is subjected to fire because the web and bottom flange have thinner cross-sections and a larger exposed perimeter than the top flange. Because of the damage caused by a fire, the overall performance of the member will be affected by deterioration of the web's material qualities. Cellular beams' fire resistance and protection have been the topic of much dispute because of their behaviour at higher temperatures, the fire protection material, and the required thickness. It was found that the buckling of the web posts of the steel section was linked to the buckling of the web posts of the cellular beams in fire tests, which resulted in two failure temperatures. The buckling of the steel segment is involved in both of these phenomena.

Xiong, et al(2021) As a result of this research, it has been established that high strength steel and ultra-high - strength concrete (UHSC) are viable alternatives to traditional strength. The abbreviations HSS and UHSC are used to identify these options. Members' sizes and weights can be reduced while they work on foundations by utilising HSS and UHSC. As a result, more usable floor space will be freed up, and building materials and labour costs will be cut in half, respectively. As a direct outcome of the action, both of these advantages will be realised. Concrete-filled steel tubular (CFST) columns are preferable than columns made of either UHSC or HSS alone, because the CFST columns are filled with concrete. These two materials work together to create a stronger and stiffer product because of their unique properties. CFST columns made with UHSC and HSS are studied in this work, which includes both experimental and analytical investigation. The authors did the majority of the work in this study. The fundamental goal of these investigations is to gain a better knowledge of the structural behaviour of CFST columns.

Varol, H., et al.(2017) In this paper, the most important design factors for using high-strength steels in building structures are looked at. In this study, there is a lot of focus on beams that are not limited on the side. A finite element model is used to figure out what happens when the temperature goes up. Research is being done on a set of beams with lengths from 500 mm to 4500 mm so that buckling curves can be made that match current design standards.

Cadoni et al.(2019) This study examined in depth the impact of sample thickness and location on its behaviour as a whole. In both dynamic and quasi-static conditions, the reduction factors of the principal mechanical properties are compared. Equations were also devised to determine how rising temperatures would affect the dynamic strength. Johnson-"constitutive Cook's parameters" for both the core and outside materials were also provided in their entirety.

Wang, Xing-Qiang, et al.(2019) The manufacturing of high-strength steel used in construction typically includes the quenching and tempering (QT) process. This is because of the benefits it provides in terms of architecture, economics, and structural design. On the other hand, temperatures that are too high have the potential to cause significant changes in the tempered martensitic microstructure of the QT steel, which in turn leads to a significant reduction in the material's mechanical properties.

Lange, Jörg, et al.(2019) Researchers looked at how steel beams behaved in hydrocarbon fires and compared them to three common situations: fully protected, moderately shielded, and not protected at all. To put it another way, beams with full protection are much less likely to catch fire than beams with only partial protection or no protection at all. This investigation found that for a partially shielded beam to fall apart in less than 30 minutes, the top of the flange must heat up to more than 600 degrees Celsius in less than a minute. This makes the building unstable during a fire disaster, when the strength and stiffness of the beams are reduced by the fire.

Methodology

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Table I. Part of the equation for the yield strength of steel in a fire

Type of members	Ambient temperature design	Fire design
Cross-sections	$\gamma_{M0} = 1.0$	$\gamma_{M,fi} = 1.0$
Members with instability	$\gamma_{M1} = 1.0$	$\gamma_{M,fi} = 1.0$
Tension members to fracture	$\gamma_{M2} = 1.25$	$\gamma_{M,fi} = 1.0$
Joints	$\gamma_{M3} = 1.25$	$\gamma_{M,fi} = 1.0$

where Xki represents the design typical or nominal value of the mechanical characteristic when it is at the normal temperature. The ratio of a material's Xf,d/Xk dimensions is a significant mechanical property that is influenced by temperature. The M,fi attribute of the material is something that should be considered in the event of a fire.

Steel used in construction can be damaged by fire.

In the event of a fire, it can be incredibly beneficial for construction managers and contractors to have a more in-depth understanding of the unique way in which structural steel reacts and maintains its integrity. As a result of having access to this information, they should now be in a position to make recommendations regarding the manner of fire protection that is compliant as well as effective.

The point at which steel begins to deform.

Before it begins to deteriorate, the maximum temperature at which structural steel can be used in an operational environment is around 425 degrees Celsius. When heated to temperatures between 600 and 650 degrees Celsius, the tensile strength of steel decreases by approximately half, making it more susceptible to fracture (depending on the load it bears). Even if a fire is restricted to one room of a house, that room alone is capable of reaching temperatures of at least 300 degrees Fahrenheit (600 degrees Celsius). It should come as no surprise that the nature of the substance that is being burned has some bearing on the topic at hand. When they burn, regular candles may only reach temperatures of 600 degrees Celsius or more, but fires fueled by propane can reach temperatures of up to 2000 degrees Celsius while they are burning.

In spite of the fact that you might believe there aren't very many big fires that pose a substantial threat to the structural integrity of structural steel, there are in fact fires that fit this description. If the strength factor of steel can be cut in half by a candle flame, then it is abundantly evident that the steel requires more processing in order to be prevented from melting.

Temperature-dependent changes in the colour of steel

Steel undergoes a process known as thermal expansion when heated to high temperatures, which alters the material's properties. Because temperature is a factor in the transformation, the substance's appearance will change. Yellowish tinges appear at temperatures between 260 and 285 degrees Celsius, followed by a spectrum of purple hues and a cool shade of blue. Red, yellow, and bright white appear at temperatures between 290 and 330 degrees Celsius. Depending on how elastic the deformations are, the steel may be able to return to its original shape once the fire has been put out or after the natural process of burning out has completed. Only when the fire has been extinguished can this occur. Regardless of whether or not the fire is out, this will happen. However, it is possible that a permanent set could form that would represent an even greater threat to the general integrity of the game. In addition to the initial load and any residual load, this hazard is also present. If this doesn't happen, it's possible that a permanent set will be created instead.

Steel constructions can be damaged by fire.

Following a blaze, one of the first things that is inspected is the building's structural steel. Because the deformations we observe are extremely unreliable methods for quantifying the structural damage produced by the fire, it is essential to have knowledge on the length of time the fire raged and the highest temperature it reached. In addition to this, the temperature at which the steel yields is quite important. It is referred to as crucial if the yield stress is lowered by sixty percent compared to when it was at room temperature (i.e. cannot support its load). It is standard procedure to determine the crucial temperature while the building is still being constructed in order to guarantee accurate regulation.

If a fire is maintained at temperatures lower than 700 degrees Celsius for less than twenty minutes, the fire's stiffness and strength will only be momentarily lessened. In consequence of this, the steel, despite the fact that it could look twisted, will straighten out after being exposed to fire and regain its original characteristics. Buckling is still a possibility, despite the fact that the steel has been deformed.

The temperature at which structural steel melts.

Carbon steel will begin to melt at a temperature of 1130 degrees Celsius, whereas carbon-free steel will not begin to melt until it reaches a temperature of 1492 degrees Celsius. At a temperature of about 1550 degrees Celsius, practically all varieties of steel will turn into a completely liquid state.

Calculations on the fire resistance of steel

In order to assess a building's fire resistance, it is necessary to consider each of these three fundamental criteria. Failure to do so will result in considerable damage to the structure. It's important to note that the "fire resistance period" of a material or product is measured in minutes.

An engineering phrase describing how much weight a steel beam can hold before cracking or yielding is known as "load-bearing capability."

Heat, fire, and smoke resistance are all aspects of steel's integrity.

Insulation refers to steel's ability to withstand rising temperatures.

What are the most recent fire safety requirements for steel in the business right now?

It is crucial to examine the structure's purpose and height when it comes to fire safety. The following two pieces of legislation are to blame for the development of these norms:

A 30-meter-tall office building without sprinklers must have a fire resistance time of at least 90 minutes.

In order for any commercial structure (such as a shop) to be safe from fire for at least 60 minutes, it must be at least 19 metres above ground.

This legislation's fire-resistance standards don't specifically include structural steel; however, these guidelines can be used to determine the best method for protecting steel structures from fire.

Steel's fire resistance can be improved.

Because structural steel is such a frequent component in both new and old construction projects, there are a variety of ways in which the fire resistance of structural steel can be improved. You will be required to make a decision between taking a reactive or a non-reactive strategy. This is based on how "reactive" high temperatures are to their ability to resist against the harm caused by fire. Cementitious coatings, on the other hand, shield steel beams from damage regardless of the weather, whereas intumescent paint swells when it is exposed to high temperatures.

Paint that is combustible and that is applied with a sprayer

When it comes to passive fire protection, intumescent steel paint is one of the alternatives that is utilised the most frequently and offers the most value for the money. This one-of-a-kind kind of paint swells up and forms a protective covering all the way around steel structures when it is subjected to heat. The addition of this layer slows down the flow of heat to the steel, which in turn increases the amount of time it takes for the steel to reach its critical temperature.

Coatings that are capable of being ignited

Steel can be protected from fire by using spray-applied fireproofing as well as film coatings that are either water- or solvent-based. They undergo a significant expansion when subjected to high temperatures. In that regard, this is analogous to combustible paint. Intumescent coatings with a thin film are the standard in the industry; however, thick film coatings, which are able to tolerate higher temperatures, are more typically encountered in industrial situations such as hydrocarbon facilities.

flammability resistant coatings applied on boards

During the course of the construction process, steel erectors have the option of putting intumescent boards to beams, columns, and decking made of steel. These planks are made from a mineral-based wood that is particularly long-lasting due to its composition. In contrast to spray-applied fireproofing, which requires additional tarping and better ventilation, intumescent board systems are an extremely cost-effective solution to improve the fire resistance of steel. This is because they do not require these additional precautions. Additionally, construction projects will be less impacted as a result of this.

Coatings that are composed of cement

Up until the 1970s, the industry generally followed the practise of using cementitious coatings to protect steel beams from the damage caused by fire. However, beginning in the 1970s, the industry began to diversify in order to meet the demand for solutions that were lighter and more versatile. Cementitious paint, on the other hand, does not expand when heated in the same way as intumescent paint does. Because they create such a substantial and multi-layered barrier between the fire and the underlying steel, all they do is delay the heat's transmission to it. Because the structural integrity of cementitious is not put at risk by excessive levels of moisture in the air, it is a great choice for locations that see low levels of precipitation.

Beams that do not have any protective coverings.

The distribution of average temperatures along the steel profiles of the three unprotected beams is depicted in Figure 4, which may be seen here. In the cross section of the steel beam, the temperatures at the top flange are, on average, the lowest; this is because the slab has a significant impact on the thermal gradient (Fig. 5). Beam 2's temperature hit its high of 795 degrees Celsius after 39 minutes had passed (Fig. 4). When the temperature of the furnace hits 730 degrees Celsius, the beam reacts in a linear fashion for approximately twenty minutes. At a temperature of 800 degrees Celsius in the furnace, the beam deflection rate is measured after approximately 24 minutes, which is an indication that the beam properties have started to deteriorate. Beam 2's deflection rate begins to grow dramatically between minutes 20 and 25, reaching its maximum at minute 39, when the beam has deflected by 249 mm at a furnace temperature of around 870 degrees Celsius. This occurs when the beam is in operation. When an ISO 834 fire breaks out, the concrete slab does not have enough time to transmit a significant amount of heat, which decreases the restraining force and causes the deflection to rapidly grow.

The fundamental causes of failure are the strength and stiffness of the steel, rather than a combination of the material qualities of both the steel and the concrete being lost.

Protected beams

Compared to beams that don't have any protection, the deflection and temperature distribution through the steel sections are shown. The protected composite cellular beams' highest temperatures were measured in the bottom web of the steel sections. These temperatures were much higher than what was allowed. When the test was over after just over an hour in the furnace, all three had reached temperatures of at least 787 °C. Figure 5 shows that the concrete slab keeps a more even temperature than the steel cellular beams. After 69 minutes, the temperature of the slab's bottom reached 429 degrees Celsius, which was the highest temperature ever measured. The data show that the temperature dropped to 101 degrees Celsius close to the surface of the concrete slab.

Conclusion

Structural steelwork is less competitive than other building materials because there are an excessive number of regulations about fire protection, and the cost of insurance for steel structures is more than the cost of insurance for concrete structures. It would be considerably simpler to build the most effective level of fire protection if the existing fire laws were rethought in order to gain a clearer concept of the fire risk and safety goals. Even if the aforementioned issues with the use of steel in buildings might have serious repercussions, there is still a lot that can be achieved from the outset of the planning process for a project provided proper fire design techniques for active or passive protection measures are established. In the framework of these techniques, the load-bearing structure should be viewed as a component of an integrated fire hazard evaluation of a building's complete active and passive fire protection. This evaluation should take place. This would make it possible to investigate the implications of trade-offs and evaluate other solutions for fire protection that provide the same level of safety but at a lower cost.

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